Urban sound design for all

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ABSTRACT

This paper reflects on the design of an urban sonic environment that meets the needs of all inhabitants. To this end, it explores the variance in hearing capabilities amongst different groups of the population relying on several recent findings in that area. Based on detailed analysis of hearing, attention, and sensitivity, it was found that there is a significant variation in the capability for focusing and gating in complex auditory environments both in the healthy population and in disease. These differences go well beyond what can be observed by the classical assessment of hearing periphery through tonal audiometry. Examples of disease considered are, attention deficits, Parkinson's, dementia, … Consideration of the differences between persons influences the expectations for public space sonic environments but may also directly influence the soundscape as perception and understanding are key elements of its definition. Urban sound design could embrace concepts as complexity and high fidelity to better cater for the needs of all groups of users of urban public places.

1. INTRODUCTION

In 20th century culture, urban environmental sound has become a nuisance that has mostly been addressed via noise pollution regulations and treated as a waste. Even today it is often the concern of environmental offices that consider it side by side with water and air pollution. Yet, the scientific views of the new century changed the paradigm to quality of the living environment and the sonic environment became an integral part of it. Hence urban sound design as an active form of creating the holistic sound environment rather than fighting some of its components has emerged. The urban sound design process should include all stakeholders and cater for the different needs of users of the space. To this end, a co-creation approach is very promising [1].

In soundscape design, it is recognised that the individual preferences and expectations of the users or future users of a space has to be accounted for [2]. The methodology for identifying these preferences and expectations is not uniquely defined and often boils down to asking the opinion of representatives of the citizens, e.g. in co-creation sessions. This approach guarantees a strong knowledge of the local specificities and sociocultural differences but risks to focus mainly on the *average person*. Vulnerable groups may be forgotten.

In this contribution, vulnerability is identified via inter-individual differences in perception of the audiovisual environment such as noise sensitivity, auditory and visual dominance, attention focussing capability. More severe vulnerabilities and stronger inter-individual differences are related to hearing,

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gating, attention, and cognitive deficits. We will argue that many of these inter-individual differences can be translated to preferred complexity of the urban sonic environment.

2. PERCEIVED AND UNDERSTOOD

The definition of soundscape: “the sonic environment as perceived and understood by people …” explicitly refers to perception, “the organization, identification, and interpretation of sensory information” and to understanding, the cognitive process of assigning meaning. Both psychology and neuroscience have tackled the problem of truly understanding these processes for years, recently helped by advanced brain imaging techniques. This also revealed deficits and disfunction related to specific personal characteristics or disease. In this section a number of these findings are highlighted.

2.1. Noise sensitivity

Noise sensitivity has been recognised as a stable personal treat that modifies the effect of extensive exposure to unwanted noise at home. Noise sensitivity is a self-perceived indicator of vulnerability to stressors in general, linked to perception of environmental threat and lack of control [3]. Twin research has shown that it is partly genetically determined [4] but the underlying mechanisms and biomarkers were only recently discovered. Kliuchko et al. [5] state that “noise sensitivity is associated with altered sound feature encoding and attenuated discrimination of sound noisiness in the auditory cortex” while Shepard et al. [6] mention reduced auditory gating as a mechanism. They base their conclusions on lectrophysiological observations of early and non-attentive stimulus responses (mismatch negativity). Brain imaging of the central auditory system revealed differences in the volume of grey matter in bilateral temporal pole, left Heschl's sulcus (HS), right anterior insula, and bilateral hippocampus in noise sensitive persons [7]. Based on known functionality of these structures, the authors speculate that “noise sensitivity is related to the ability to form the associations between negative emotional experience and noise”.

Taken together, this new evidence on the neurological basis of noise sensitivity, could lead to the conclusion that noise sensitive people at the one hand are less capable of gating out unwanted or non-informative sound while at the other hand they may associate these unwanted sounds more strongly with emotional experience. Noise sensitive people may therefore prefer less complex sonic environments with high fidelity, that is where each sound has its clear and distinguishable characteristic.

2.2. Hearing

In a naïve view, hearing damage may be identified with a higher sensory threshold and therefore also reduced requirements for the sonic environment or lower sensitivity to unwanted sound. However, this naïve view is incorrect. On the contrary, an increased hearing threshold leads to disentangle target sound, mostly speech, from the background. Unilateral hearing loss reduces the capability of spatially separating sound sources, which may occasionally be partly replaced by the use of spectral cues. But even in persons with normal tonal audiometry, auditory neuropathy, “a range of disease mechanisms that typically disrupt the synaptic encoding and/or neural transmission of auditory information in the cochlea and auditory nerve”, may impair speech comprehension significantly [8] and by extension also the comprehension of elements of the sonic environment. Thus even persons with hearing loss that could not be diagnosed via tonal threshold audiometry may observe difficulties in analysing the auditory scene.

2.3. Auditory and visual attention

Listening to the sound is seldomly the purpose of visiting a public place, hence many sounds remain unattended. Only the sufficiently salient sound events may capture the attention of the urban dweller and change its listening style and appreciation of the sonic environment [9]. Based on this observation, we proposed a soundscape classification model that includes “backgrounded” sound environments [10]. Yet, it is well-known that attention is multisensory and some of the neural circuitry for visual and auditory saliency and attention overlaps. Hence, at least part of the observed influence of visual surroundings on loudness, soundscape pleasantness[11], and annoyance [12], may be explained by attention. Psychological research has shown that some persons are auditory dominant and some are visual dominant in multisensory object integration [13]. We have proposed this inter-individual difference as in auditory or visual dominance and the susceptibility to inattentional blindness as a possible explanation for some of the mixed findings in the effect of greening and source visibility on the perception of auditory stimuli [14].

The above-mentioned personal differences in perception of an audio-visual environment should be taken into consideration when exploring the needs and preferences of the users of a space regarding its sonic environment. Due to the lack of attention for the auditory stimulus, an acoustic intervention may need to be much more prominent compared to the visual setting that it accompanies than the acoustician – by trade a person that is auditory dominant – that designs it may expect. Lowering the level of unwanted noise at the expense of visual intrusion may not have the desired effect [15].

2.4. Attention deficits, Parkinson’s, dementia

Persons with mental illness need special care when designing an appropriate sonic environment. Unfortunately, our understanding of auditory processing in this special group is far from complete. Auditory processing disorders (mainly measured in children) are mostly related to cognitive and attention issues rather than bottom-up auditory processing [16]. Recently we conducted a systematic review on auditory processing in Parkinson’s disease [17] and concluded that “the current findings on auditory gating, selective auditory attention and the P3a appear to demonstrate an impairment related to the efficient filtering of information at multiple stages of central auditory processing in patients with PD”.

Thus, when designing outdoor or indoor spaces catering for these special groups, a multitude of auditory stimuli should be avoided. Such a complex environment would likely hinder them in understanding the sonic environment and prohibit verbal communication.

Dementia is increasingly common in aging populations. Persons with dementia may suffer from impaired perception of auditory scenes and objects as well as impaired recognition of sounds [18]. They may therefore avoid or dislike busy sound environments but may still appreciate music and recognise melody. Moreover, research on the underlying physiological system [19] argues that “if the damaged semantic system cannot identify potentially meaningful sounds, then this unresolved ambiguity may render such sounds behaviourally salient”. There are nevertheless some variations in depending on the form of dementia. This and other evidence has led us to suggest specifically tuned soundscapes for nursing homes housing persons with dementia [20].

3. COMPLEXITY

Predictability is a key element in liking a sound experience such as music [21]. The working hypothesis is that the superior temporal cortex stores auditory templates that can later be retrieved for predicting while this sequencing is organised at a higher level in frontal cortices. Positive prediction error is then associated with pleasure and liking. Music remains pleasurable even after hearing it many times because it has a certain degree of complexity. More generally, it has been observed that complexity (of time series) and can be interpreted in terms of predictability [22]. Very low complexity leads to perfect predictions and does not trigger the pleasure related to positive prediction error, but very high complexity prohibits prediction completely and thus also does not result in a pleasurable experience. Early music theories explored this complexity in terms of level and pitch changes and this theory has also been translated to urban sound environments [23].

Predictability at a higher level of abstraction was already identified above as an important aspect of music listening, yet its importance goes beyond. Humans are driven by a knowledge instinct [24] to increase the predictability of their environment. Prediction error not only drives surprise and may trigger attention, but it also stimulates associative learning [25]. However, the amount of prediction error matters. If the environment is completely unpredictable, no learning could occur. Likewise, if the environment is completely predictable, there is no need for learning either. Finally, learning creates a aesthetic emotion and pleasure [24]. This higher level of predictability and complexity of the sonic environment will be referred to as symbolic complexity. In contrast to signal complexity it has to be interpreted as the sequence of auditory objects that emerge while interpreting a sonic environment. Humming and buzzing sounds from multiple mechanic sources together may create high symbolic complexity while signal complexity is rather low. The combination of car sounds with music, birds, and people talking in a park would categorise as highly complex both at the signal and at the symbol level.

When contrasting the complexity framework to the popular model for soundscape evaluation based on the circumplex model of affect [26][27], the main focus of the complexity framework seems to be on the *valence* axis where the optimal level of complexity would lead to positive valence. And as explained above this optimal level depends on the hearing, gating, attention, and cognitive abilities of the person. One may however also detect some resemblance between high symbolic complexity and *arousal* through multiple stimuli creating a feeling of liveliness.

4. DISCUSSION AND CONCLUSIONS

This manuscript argues that urban sound design should cater for persons with different needs and explores how personal treats such as noise sensitivity and auditory processing deficits, attention deficits and cognitive deficits may affect the preferred sonic environment. It also proposes that complexity of the sonic environment both in terms of signal complexity, explored in the auditory cortex, and symbolic complexity, explored in the frontal cortices, as a useful framework for this differentiation.

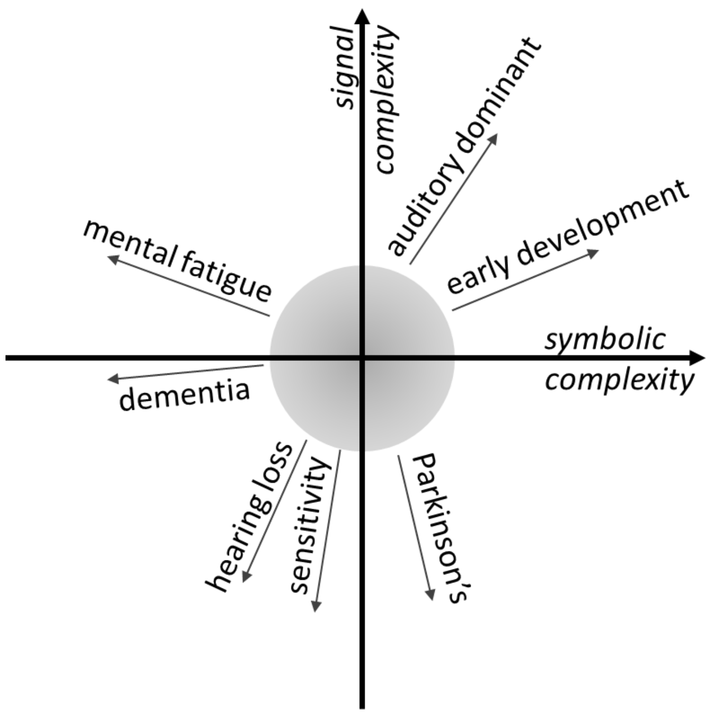

Figure 1. Optimal complexity of the sonic environment shown as a grey area in the symbolic versus signal complexity plane; arrows indicate how the optimal area would move for different target groups.

Figure 1 summarised these findings. The figure shows the optimal region for a broad audience as a greyish area at moderate signal complexity (e.g. music like) and at moderate symbolic complexity (e.g. a moderate amount of different sound sources). Low signal complexity may be preferred by persons that have difficulties to disentangle complex acoustic signals into its auditory objects because of a lower gating and primary attention focussing capability that may be due to illness. Hearing loss may additionally reduce the capability for binaural auditory scene analysis. At the other side of the spectrum persons with a strong auditory focus (e.g. musicians) may prefer more complex auditory stimuli to maintain their interest and liking of the sonic environment. When turning to symbolic complexity, where frontal cortices and cognition play an important role, children and youngsters during early development may crave complex environments with multiple different stimuli as it gives them opportunities for learning and shaping their plastic central nervous system. At the other end of the scale, persons with reduced cognitive abilities such as persons suffering from dementia may benefit from clear, single source environments that are easy to interpret. Mental fatigue may temporarily lead to similar demands. Hence urban restorative spaces could also benefit from low symbolic complexity (few identifiable sounds at the same time) but limited predictability at the signal level to provide a continuous trigger for attention.

A conceptual way to describe the above-mentioned differences between persons is by acknowledging that the soundscape associated to the sonic environment in a place is different for different persons as they perceive and understand the sonic environment differently. This is specifically the case if they suffer from auditory deficits, attention deficits, or cognitive deficits.

Although the explained complexity framework is conceptually simple and understandable for practitioners, measuring it remains a challenge. Where signal complexity could be based on coherence and novelty in signal amplitude or better still in signal saliency, symbol complexity requires giving meaning to the sounds, which remains a challenge even for today's artificial intelligence systems.

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